Concept for structure and control of a metamorphic 3D transport system for large and complex buildings

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Abstract

This article presents the concept for a transport system (TS) that meets the requirements of mobile and parallel structures in compex and intelligent buildings. Different from contemporary transport systems the act of transporting is decentralized and parallized. The system uses small autonomous transport units (TU) that have the capability of adapting to path planning changes and can be combined to bigger units. These transport units can move freely on a linked path network. In addition to a central control unit that manages the complex path planning each unit obtains a certain intelligence. After take-off the TU's computer completely takes over the control and is able to change the the unit's movements conforming to certain strategies. Information about the other units' status quo can be obtained from a virtual model of the TS's state. The TU's communicate with this model in order to add or retrieve data information vital for their movements. Furthermore the units are displayed in the model via software agents that show the way to their real companions.

1. Introduction

Especially with big multifunctional buildings a problem besides the one of an appropriate facility management occurs more and more frequently: the problem of transportation. Already during construction and even more while everyday business in office buildings, congress centres or airports takes place huge amounts of goods, material or people have to be moved. The desired multifunctionality of the building adds to complexity of the problem. Time requirements for planning and controlling this flow of material and people are enormous. In addition to this classic one-dimensional transport systems like elevators, conveyor belts or cranes have obviously reached their limits of capacity. Even nowadays Elevator shafts take up a high percentage of the usable surface. Increasing the number of floors has become less economical. Thus it is important to combine and to paralize transport systems - a new generation of transport systems that are volume-oriented and meet the requirements in capacity, speed and flexibility. A system that is capable of adapting to frequently changing environments also demands a whole new concept of control and information that deals with the enormously (because of the linking) increased planning and control tasks.

2. First reflections

Today's Transport situation is characterized by centrally placed, one-dimensional transport systems (TS). Among the most common vertical systems are groups of elevators, for large amounts of horizontal distributions conveyor belts are used as well. These systems have the advantage of large transport capacities. The subsequent individual distribution of goods and people is done conventionally: manually, without the use of a sophisticated TS. Such a systems implies the distinction between central (CP) and decentral parts (DP) of the building. A characteristic for the CPs is a quick and well functioning link to the transport system so the whole transportation flow must pass this center. In some cases this can be a desired effect yet normally leads to the problem of overstressing these areas. The decentral areas have the advantage that only a few goods or people are passed through them, however, access is difficult and costs a lot of time.

Because of an increasing need for flexible use and expansion of modern buildings standardized and modular components are used more and more frequently. The trend towards a fully automatic construction of such buildings demands the use of standardized elemtary cells as well. This leads to a new building concept that is the basis for the new transport system. On the following pages we will try to draw a conclusion from a high niveau of abstraction to precise requirements for the TS.

In an ideal building all parts are equally important. If we divide the building in units of the same volume figure 1 illustrates the idea of a new building philosophy.

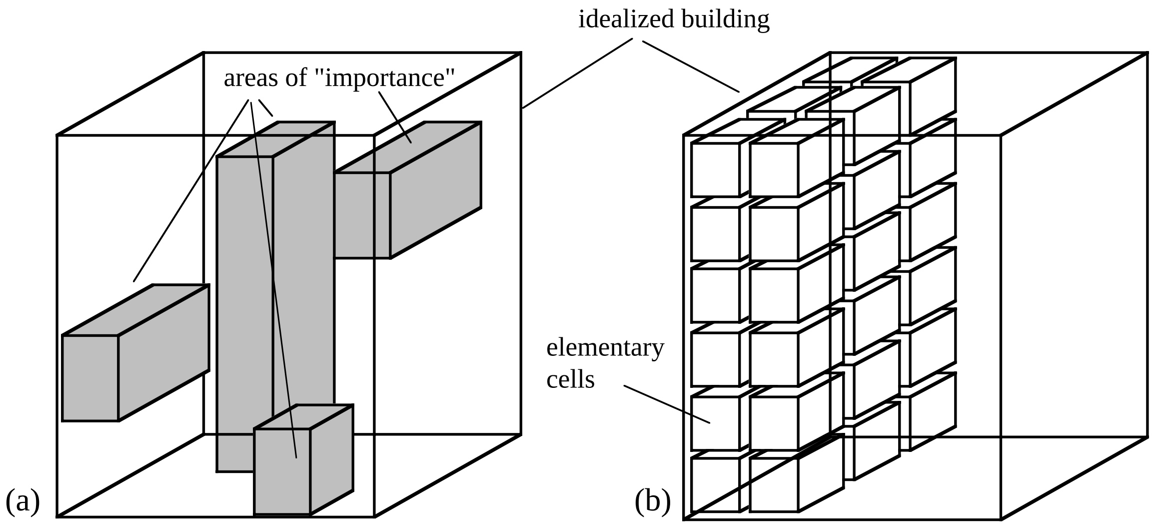


Fig.1: Abstraction of the building by dividing it into elementary cells

Figure 1a shows the traditional division of the building into fixed parts of great and small importance. Figure 1b shows the division into equally important units of the same volume. Obviously the concept of modularisation and standardization is taken into consideration here.

Of course the idea of modularisation is not totally new, yet it is the basis for understanding the new transport system. First requirements for the TS can be derived from it :

- *all elementary cells must have a connection of equal quality and capacity*
- *the TS must be usable in each elementary cell*
- *any possibility of enlargment*

Since different parts of the building have different functions, the amounts of things to be transported vary within the building. The modular concept makes it possible to combine a number of elementary cells towards functional and thematic groups and to create logical structures within the building. Figure 2 shows the functional division of the building as seen in different phases of the specific use. Ohter elementary cells have been blanked in order to provide clarity within the outline.

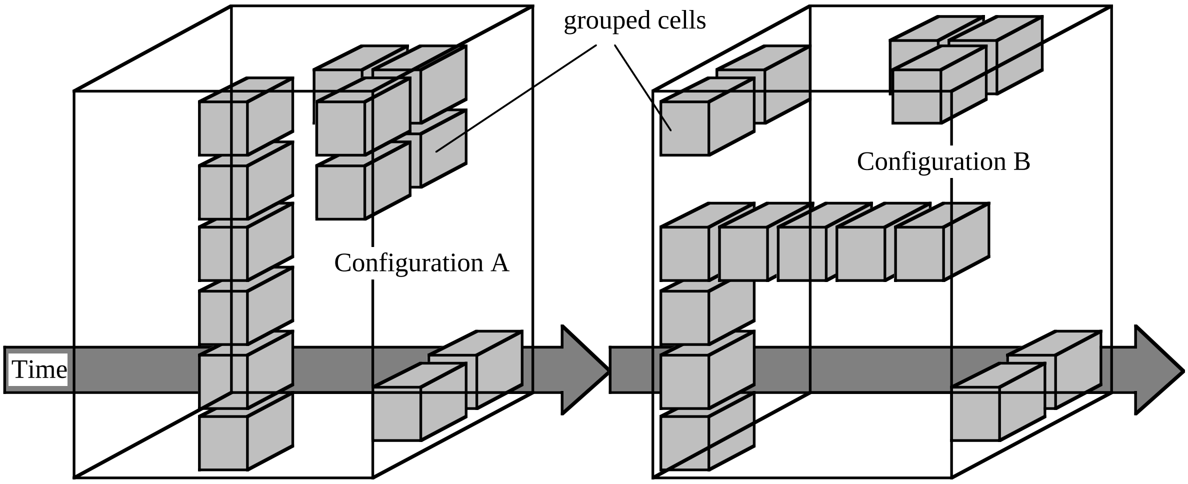


Fig. 2: changing the functional grouping of the elementary cells

The requirements upon flexible usage and expansion of the elemntary cell groups - and hence the groups themselves - change both in spatial and temporal ways : they are metamorphic. This quality is enhanced by the need for a long usage of the building because of the amount of investions involved. Yet long usage of the building implies its ability to meet constantly changing usage requirements. However, a sufficient time interval for changing the grouping of the cells has to be guaranteed since each new arrangement of the cells is accompanied by an expense that has to be justified.

All this has to be taken into consideration for the creating of the TS:

- *the TS must be able to adapt to functional and thematic groupings of the elementary cells in mid-range time intervals*

Furthermore there are of course some requirements upon the TS that change in smaller time intervals, caused by the daily rush hour for example. In order to meet these requirements

- *the transportation flow within the TS must be adjustable in spatial and capacitive ways in short time intervals.*

While the building is under construction, a considerable amount of goods and people in close relationship towards the building has already to be transported. Therefore it would be a good idea to use the TS already during construction phase as well, especially while the interior work is done. This would save expenses for a TS exclusively installed for construction. The flow of material would improve, expenses would be avoided. Possibly these saved expenses would already suffice to finance the additional costs of using a sophisticated TS instead of coventional solutions. Hence

- *the TS has already to be installed during carcase work and taken into operation section by section.*

Considering the above formulated theoritical requirements a system concept can be derived that ideally meets all of the requirements. This of course will not always be possible since some the requirements are contrary to each other. If such a case should occur acceptable compromises have to be looked for.

3. Concept of realisation

In the following I will explain the concept of the transport system trying to point out the links between different phases of development and the above derived requirements. In this article I will concentrate on the discussion of the structural concept therefore neglecting all aspects of a technical realization.

Taking a close look at the above mentioned concept of elementary cells leads us to a first structural conception of the TS. The whole TS has to be resolved into non-divisible units which are called „transport units“ (TU). These TUs move on fixed one-dimensional paths. The expansion of the TS from a one- into a three-dimensional system is achieved by installing paths of certain direction (here: x-, y-, and z-direction). That way a voluminal grid structure is created. The single paths are linked via their cross points (CP). Choosing the right distance between the paths, each elemntary cell can be served by the TUs. The proportion between the surface of the elementary cells and the surface needed for the installation of the TS remains constant. Hence the TS's surface needs increase proportionally to the expanded usable surface and a disparity between usable surface and surface needed for transportation is avoided. Figure 3 shows a TU on a one-dimensional path and the expansion towards a three-dimensional system.

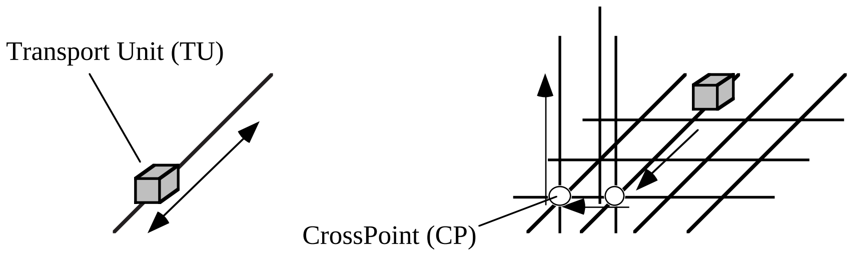


Fig. 3 : creation of a three-dimensional system by linking

By using a large number of TUs and hence parallelizing the task of transportation and using a very large number of paths each part of the building can be served according to its needs.

It is very important to note that the TS is a homogeneous one since combining parts of different transport systems may cause connection and transfer problems which would then result into unnecessary time lags and avoidable expenses. The homogeneity of the TS is also an important condition for future installation of additional applications to an existing system.

In order to avoid collisions between the TUs paths next to each other alternate in their direction. Of course it would as well be possible to use bi-directional paths and realize the collision chechs via software. Yet even the usage of a small number of TUs would already result into an unacceptable computing affort caused by the need for an appropriate path planning. During the occuring time-lag the TUs would block each other. As a consequence the number of TUs in use would not depend on the amount of things to be transported but on the capacities of the responsible computers. This effect clearly contradicts the demand for unlimited resources for expansion. Another disadvantage would be the numerous changes in direction which would disrupt the continuity traffic.

Especially with the z-direction the principle of uni-directional paths is a decisive improvement. If one takes a close look at a „traditonal“ elevator system it becomes obvious that because of the bi-directionality one TU at a time can be placed on the whole transport path. And what is more, the goods and people to be transported all have different starting points and destinations, hence the effectiveness of such an elevator system declines with its length. Increasing the capacity and reducing the time of waiting can only be achieved by increasing the number of elevator systems. Uni-directional systems, however, ideally support room for transport equally distributed to each part of the path. Hence the transport capacity increases with ascending length without any need for further surface area. This principle has already been realized with the „Paternoster“-systems. Figure 4 shows a bi- and an uni-directional system which take up the same amount of surface area.

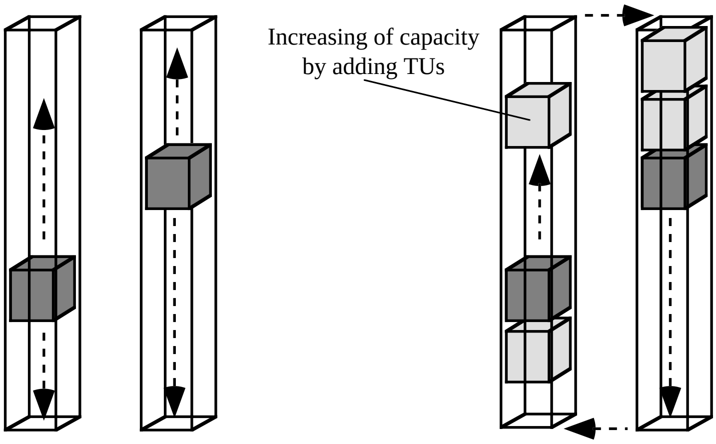


Fig. 4: Comparing bi- and uni-directional elevator systems

Using an uni-directional systems the transport capacity can be enhanced by adding further TUs.

In order to serve the elementary cells directly without any detours each cell should be accessible from all directions. In a „one-way“-system avoiding detours is crucial since the resulting unnecessary moves by the TUs take up a good deal of the system's effectiveness. Figure 5 illustrates uni- and bidirectional movements in a two-dimensional TS.

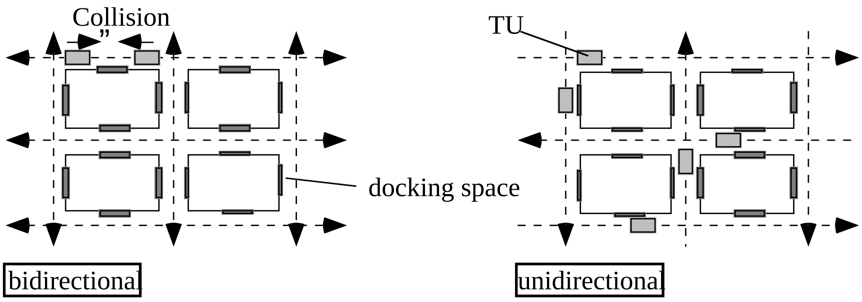


Fig 5: Uni-directional paths avoid collisions

In theory the transport capacity in frequently accessed parts of a building (such as restaurants, galeries etc.) can be increased without any limits by increasing the number of the TUs used. In such areas it makes more sense to create circular path systems, on which a number (which depends on the capacity needed) of TUs move permanently. The used CP's have to be modified in order to guarantee a troouble-free performance. Special ramps which which make it possible to access moving TUs could be developed. This would save a lot of energy otherwise needed by the TU for braking and accelerating. Plus the capacity of the system would be considerably increased. However, these new path systems are still usable by other TUs yet with the circulating TUs having a higher priority. Figure 6 shows the creation of such a circular, closed system which connects the grey-coloured important areas of the building. Since in an ideal case the whole path can be covered with TUs, circular systems like this one offer maximum transport capacities per area and time used. In the two-dimensional case such a system has already been realized in the form of luggage transportation systems e.g. in airports or (in z-direction) in form of the „PATERNOSTER“. Our system enables us to create such closed structures three-dimensional ways as well.

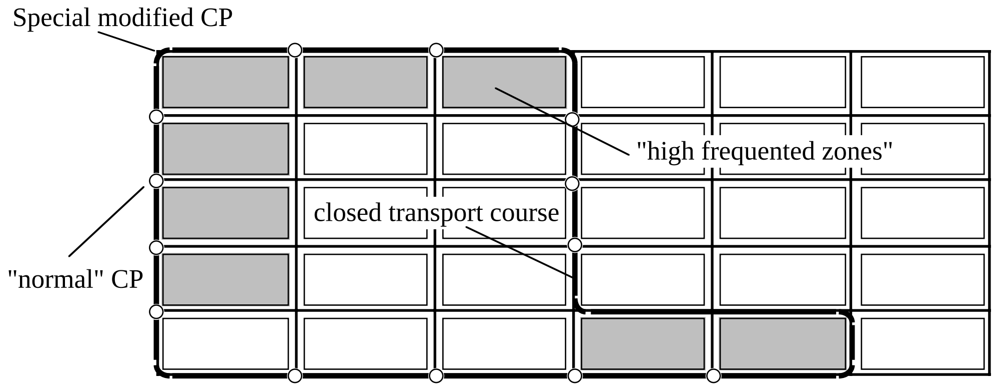


Fig 6: two-dimensional closed path system

The CPs modified for the usage within the circular systems are reserved for that purpose - other TUs are no longer able to use these crossings. Yet all other „normal“ CPs remain open and can be accessed in any way whatever.

Since the modification of the CPs costs time and money it only makes sense economically and technically if the functional grouping of the cells is consistant during a certain medium-range time periods. In addition to these medium- and long-term changes within the transportation flow there are short-term changes as well, for example caused by the daily rush-hour.

In order to be able to deal with those changes facilities for the creation of „transport unit groups“ have to be supplied. These TUGs are considered as single TUs with a higher priority to them. This comprises a number of advantages :

- *TUGs assert themselves against single TUs during path planning and choose the quickest and shortest way.*
- *TUGs do not require additional controlling while supplying multiple transport capacities.*
- *since they possess priority at the CPs,TUGs are able to go at a constant pace without any delays*

Figure 7 shows a TU which waits for a TUG to pass by.

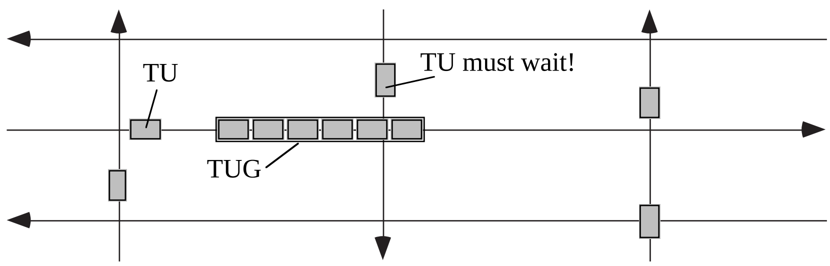


Fig. 7: TUGs possess higher priority at cross-points

It is important not to view TUGs as physically enlarged TUs but as a group of TUs treated temporarily as a logical unit. The logical assignment can be initiated by the TUs themselves as well. On the way from the starting to the destination point it becomes a task for the TU to find partners for a TUG in order to increase its level of priority. It is also possible for the TU to spend parts of its way within a TUG and then again seperate from the other TUs. This is shown in Figure 8.

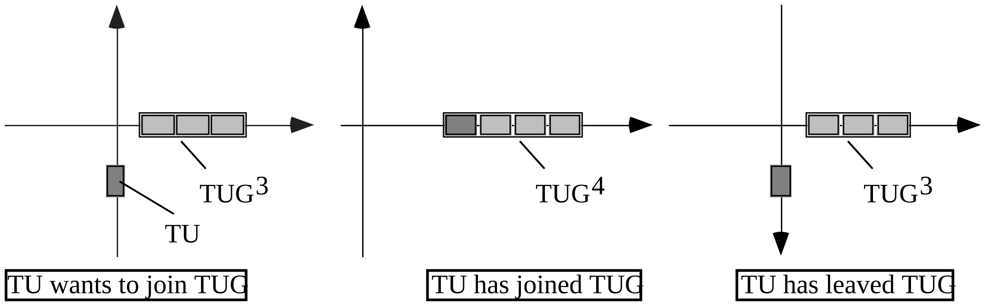


Fig. 8: A TU temporarily joins a TUG

The last requirement for the system to meet is its usability during the construction of the building. However, this has consequences rather for the system's implementation rather than for its structure since the above explained functionality almost ideally supports transports during construction. Hence the TUs have to be robust in order to meet the requirements of both the construction and everyday environments.

4. Concept for control

Because of the large number of TUs and the extremely large number of possible paths between the starting and destination points a single central control unit for all TUs fails to fulfill the computing time demands. Hence the control task is divided into three parts: a central control unit, a smaller control unit on each TU that autonomously controls the TU while it is on its way to the destination point and a computer with the single task of manage a virtual copy of the TS.

4.1. Central control unit

The central control unit (CCU) basically serves three purposes. The first one is the registration and transmission of all calls for TUs. Having received such a call, the CCU looks for one or more TUs which are suitable for carrying out the transport task. These TUs are ordered to the place the call came from. At the same time the CCU uses genetic search algorithms in order to find the shortest and quickest way possible between starting and destination point. Doing this the status of the TS, the existance of closed path systems and other facts have to be taken into consideration. The way the „status quo“ of the system can be reproduced visually will be explained later. The result of the algorithms' application is dispatched to the TU which is then given a starting signal. Furthermore the CCU in the role of the highest authority within system has to solve all deadlock situations which could be caused by the TUs' individual path planning.

4.2. Local control units for the TU

Each TU has its own control unit which totally controls it after take-off. Each TU is able to communicate with the CCU and other TUs via an information network. The local computer's main task is of course to ensure the well-functioning of the TU. While the TU is on its way the local control unit constantly supervises the path planned by the CCU. If there are any signs for a possible delay, an accumulation of TUs or other unfavourable events it autonomously changes the path planning. Any information concerning the state of the TS in the TU's nearer surrounding is supplied by the computer that manages the virtual copy of the TS. Each unit has the opportunity to leave its own agent within that computer which then is able to preventatively go through all possibly occuring situations.

4.3. VIRTUAL SIMULATION PLATFORM

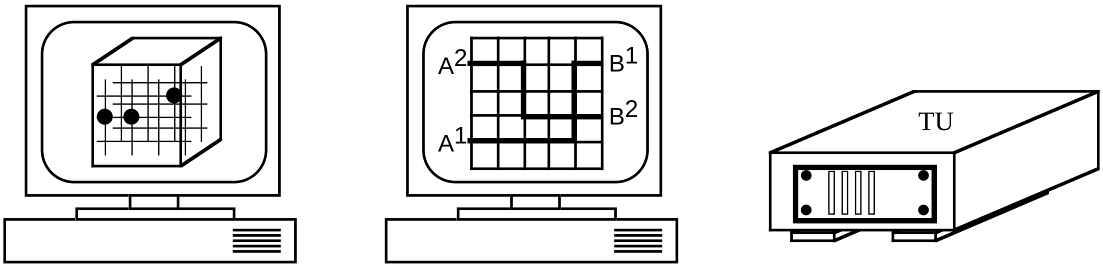
This computer performs two tasks. One is to store the current status of the TS as a whole. This includes the position, the velocity, the moment of arrival and the calls for groupings of the single TUs. The data is organized according to the geometric specifics of the building. This means that e.g. the information about time of arrival and calls for groupings are stored in linkage to the CPs affected. As a result the path planning for single TUs is done from CP to CP, the path required for the TUs' movement is reserved.

In addition to the plain storage of the TS's status the platform also supplies a virtual „playground“. In the process the TS is simulated with all its relevant information. Each TU is able to place an agent within the virtual TS that goes through different movement scenarios along with the agents by other TUs. It is possible for the agents to follow different kinds of strategies, for example a „survival-strategy“ with the task of reaching the destination point as quickly as possible without any consideration for other TUs or a „cooperative strategy“ trying to find an optimal solution for the TS as a whole.

Then only the functioning of the communication between the TU and its agent has to be guaranteed for the agent being able to guide the TU through the real TS as well.

Another advantage would be the opportunity to test long-term changes within the TS (such as the installation of circular structures) before they're actually realized by simulating them within the virtual TS.

Figure 9 shows the three components for the control of the TS.



virtual-simulation-system main-control local control unit

Fig.9: Dividing the control system into three components

5. What else could be done with the system

The above described system with its freely usable paths and small autonomous TUs is an almost ideal basis for the usage of sophistcated service systems. Intelligent service terminals are able to communicate directly with a central computer system that makes the plans for the services and asks the TS for according transport capacities.

Due to the fact that the TU moves from the starting to the destination point without the transported goods having to be transferred between several TUs those goods can easily be distributed automatically. Also service- or diagnostics-robots could use the TS to transport themselves to the places where they then perform their missions.

These few examples already show the enormous number of usable applications for such a system once an according infrastructure has been provided.

6. Summary

Within this article we introduced the concept for a transport system that is easily expandable, provides a constant ratio between occupied space and available transport capacities, enables the combination of transport capacities in temporary and spatial ways and can already be used while the building is still under construction. The main idea behind the system is its division into smaller autonomous transport units. This way goods and people can be transported to any place within the building without having to switch between different transport units. Large transport streams are managed by combining a certain number of TUs to circular structures which enormously increase the transport volume per time unit.

The problem of increased demands for control and planning tasks is solved by dividing the control system into three units. The paths for the TUs are planned centrally once, the result is a path description that is conveyed to the TUs. Once on their way the TUs are able to autonomously change their paths. All the information needed to perform these changes, e.g. the positions of others TUs, are supplied by a virtual simulation of the TS. In addition to simple request data from this simulation each TU is also able to place an agent in it which then seraches the virtual TS for optimal paths and accordingly guides the TU through the real TS.

Technical details like the realization of the path system, crossing points or design of the TUs are not dealt with in this article.